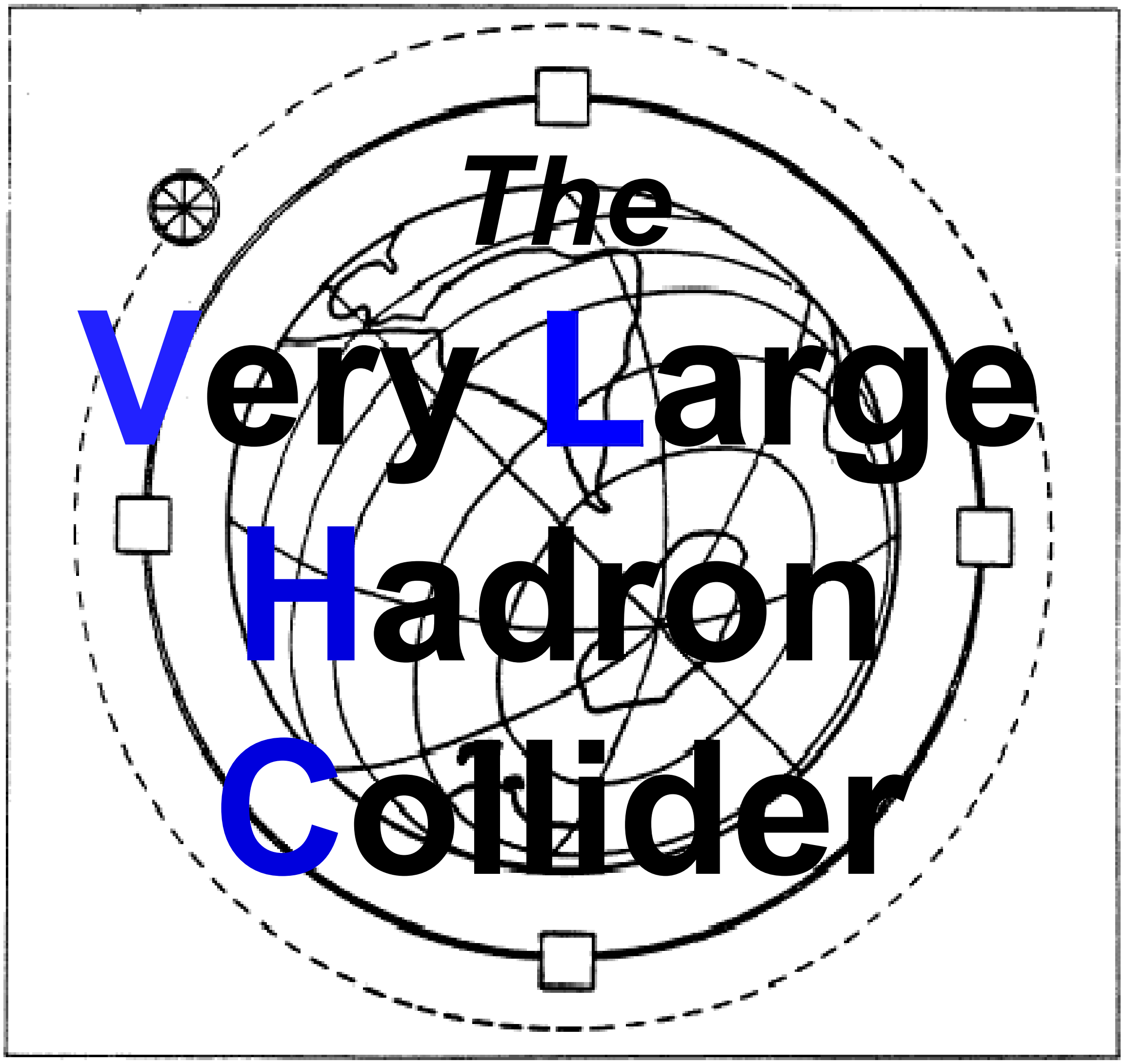

From a 1954 Slide by Enrico Fermi, University of Chicago Special Collections.

What is the VLHC Collaboration?

Ernest Malamud

Fermi National Accelerator Laboratory

VLHC Annual Meeting, Monterey, CA

June 28, 1999

Outline

- History and formation of the

"Steering Committee
for a
Future very large hadron collider"

- Why build the vlhc?
- Magnets: the heart of the matter

Different paths to a common goal

- Accelerator physics considerations
- Comments on a U.S. site at Fermilab
- Conclusions

Post-SSC and pre-Gilman Panel

Discussions of the next "energy frontier" collider

Indianapolis '94: the role of radiation damping

"New low-cost approaches to High Energy Hadron Colliders at Fermilab." Mini-Symposia. 1996 APS Annual Meeting, Indianapolis.

Snowmass '96

Very Large Hadron Collider Physics and Detector Workshop. March 13-15, 1997. Fermilab

"Accelerator Physics Issues in Future Hadron Colliders." "Hadron Colliders Beyond the LHC." Mini-Symposia. 1998 APS Annual Meeting, Columbus.

Steering committee for a future very large hadron collider

From recommendations of the HEPAP Subpanel Report on "Planning for the Future of U.S. High-Energy Physics, February 1998. (Gilman Panel)

………..recommends an expanded program of R&D on cost reduction strategies, enabling technologies, and accelerator physics issues for a VLHC.

These efforts should be coordinated across laboratory and university groups with the aim of identifying design concepts for an economically and technically viable facility.

The Steering Committee was formed in response to this recommendation.

At the initiative of John Peoples, representatives from BNL, FNAL, and LBNL (including leaders of the U. S. LHC Accelerator Project) met informally at Fermilab on **February 25, 1998** to discuss the formation of an organization to coordinate and bring coherence into the U.S. efforts on a very large hadron collider.

John Peoples asked the Directors of BNL, LBNL and Cornell University's Laboratory of Nuclear Studies to appoint representatives to a Steering Committee to organize this effort.

Appointed were:

BNL: Michael Harrison (harrison@bnl.gov)
  Stephen Peggs (peggs1@bnl.gov)
FNAL: Peter Limon (pjlimon@fnal.gov)
  Ernest Malamud (malamud@fnal.gov)
LBNL: William A. Barletta (WABarletta@lbl.gov)
  James L. Siegrist (JLSiegrist@lbl.gov)
Cornell: Gerry Dugan (dugan@lns62.lns.cornell.edu)

This group met at Fermilab **April 24, 1998** and adopted a Mission statement and a charge:

Mission Statement

The Steering committee for a future very large hadron collider coordinates efforts in the United States to achieve a superconducting proton-proton collider with approximately 100 TeV cm and approximately 10^{34} $cm^{-2}sec^{-1}$ luminosity.

The U.S. site of the vlhc is assumed to be Fermilab.

Using a nominal 20x in dynamic range:
  150 GeV MI _ 3 TeV vlhc Booster
  3 TeV vlhc Booster _ 50 TeV vlhc

Steering committee
for a future very large hadron collider

Charge (excerpts)

The Steering Committee for a future very large hadron collider has been established to coordinate the U.S. effort towards a future, post-LHC, large hadron collider.

The Steering Committee does not manage the work of the individual institutions.

The Steering Committee will

- encourage the exchange of personnel between participating institutions
- promote coordination in planning and sharing of research facilities
- provide a mechanism for all interested parties to participate in the evaluation of the alternative technological approaches that are presently being pursued.

The focus is on technology and cost reduction.

* The Steering Committee will organize the selection of a good name and logo for the vlhc.

Steering committee
for a future very large hadron collider

Working Groups

They are open to all and **participation is welcomed from all foreign and U.S. institutions**.

Magnet technologies
Accelerator technologies
Accelerator physics

Charge to working groups

Guided by the Snowmass '96 parameter sets explore and develop innovative concepts that will result in significant cost reductions.

Review progress in magnet R&D. Develop bases including costs for comparing different designs.

Monitor, encourage and coordinate progress in materials development.

Explore the viability of the various parameters sets implied by the major magnet options.

Foster dialog and partnerships with industry.

Steering committee
for a future very large hadron collider

The Steering Committee (subsequent to the April organization meeting) met 3 times:

- July 25, 1998 at BNL together with the co-convenors to define the 3 workshops and plan the August 24 HEPAP presentation.
- November 17, 1998 at Port Jefferson.
- March 28, 1999 in New York (before PAC99) to plan this meeting.

Each working group has now held a workshop.

Magnet Technologies

Co-convenors:

Bill Foster, Ron Scanlan, Peter Wanderer

"Magnets for a Very Large Hadron Collider,"

Port Jefferson, LI, NY, Nov. 16-18, 1998,
Peter Wanderer, Chair

Accelerator Technologies

Co-convenors:

Chris Leemann, Waldo Mackay, John Marriner

"VLHC Workshop on Accelerator Technology,"

Thomas Jefferson National Accelerator Facility,
Newport News, VA, Feb. 8-11, 1999
John Marriner, Chair

Accelerator Physics

Co-convenors:

Alan Jackson, Shekhar Mishra, Mike Syphers

"VLHC Workshop on Accelerator Physics,"

The Abbey, Fontana, WI, Feb. 22-25, 1999
Mike Syphers, Chair

- We are now beginning our annual meeting.

- From this meeting and the workshops will emerge an **Annual Report** setting R&D goals for the next year.

- The Steering Committee and the Workshop Co-convenors will discuss parameters for the next set of workshops. **All suggestions are welcome!**

- Discussions are underway to enlarge the membership of the Steering Committee.

Compilations of reports and transparencies

Reference copies here

Papers at PAC99

Proceedings of the 3-workshops

http://vlhc.org

Compilation of papers including

"Pink" Book. Selected Reports submitted to Snowmass '96.

"Turquoise" Book. Information Packet. Jan. '98

(submitted to the Gilman panel)

http://www-ap.fnal.gov/VLHC/

Why VLHC?

- Hadron Colliders are the "Discovery Machines" for HEP.

- They probe deeper than any other type of accelerator.

  - The W and Z were first observed at the SppS.
  - The top quark was discovered at the Tevatron.
  - It may be possible to discover Light Higgs and SUSY particles at the Tevatron in Run II.
  - LHC will extend the mass reach with 7x in E_{cm}.

Luminosity

“Eichten, Hinchliffe, Lane, Quigg” (1984) made the case for a rich physics menu for the SSC at 40 TeV E_{cm} and 10^{33}.

A 100 TeV vlhc is a factor of $(2.5)^2 = 6.25$ in s. Thus 10^{34} is the appropriate figure to set as a working parameter.

The discovery reach of such a machine is enormous.

The “Giant Microscope” and Public Support

We need to learn how to communicate better to our constituencies.

The giant “microscope” metaphor is one way.

At 10^{34} a 100 TeV vlhc can “see” contact interactions at a scale of >32 TeV (Bauer & Eno),

. . . . perhaps as high as the E_{cm} or $\Lambda_c \sim 100$ TeV

$$1/\Lambda_c \sim 2 \times 10^{-19} \text{ cm}$$

$$\sigma \sim 1/\Lambda_c^2 \sim 40 \text{ fb}$$

1 year (30% duty cycle) at 10^{34} yields 100 fb^{-1} or 4000 events

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Today the luminosity of 10^{34} is detector limited.

With history as a guide, one or two decades after the machine has operated at 10^{34}, major detector and accelerator upgrades will take place raising the luminosity to 10^{35} or higher.

The main accelerator upgrade may be to the abort system because of the large stored energy in the beam; however, by then it is likely that brighter beams will be achieved by new cooling methods, making this problem easier to cope with.

Magnets: the heart of the matter

The Snowmass parameter sets were proposed 3 years ago and there has been evolution since then. High-field magnets using NbTi conductor and operating at 1.8K (extrapolation of LHC) are not being pursued. Nor are medium field SSC type magnets being considered as an option for the vlhc.

Factors in Choosing the magnet strength

- collider energy
- accelerator physics issues
- superconducting material availability and cost
- magnet costs
- synchrotron radiation

<u>choosing the collider energy allows one to examine the role of synchrotron radiation in more detail</u>

<u>For a 50 TeV + 50 TeV collider</u>

Low-field (2.0 T superferric):

- Damping time too long to be helpful
- However, allows alternating gradient structure with no problems from anti-damping

High-field (> 10 T):

- synchrotron radiation puts power into the cryogenics
- synchrotron radiation makes the beam emittance smaller

Other factors that need evaluation to properly understand the role of synchrotron radiation:

- ground motion
- dipole field noise
- intra-beam scattering
- quantum fluctuations in the synchrotron radiation
- fill and ramp times (before synchrotron radiation comes into play)

Magnet R&D programs:
different paths to a common goal

Superconductors

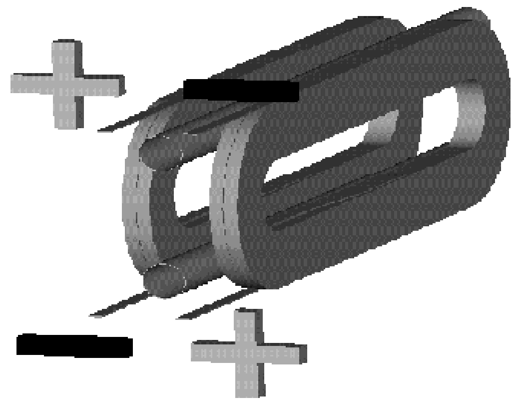
Low field

- NbTi is ideal for the low-field vlhc
- J_c at low field has increased 10x since Tevatron built (driven by MRI market)
- Cost is probably < $1 /kA-meter

High, very high field Material development is the key issue

- HTS: BSSCO, YBCO
- LTS: (A15 Conductors) Nb_3Sn, Nb_3Al

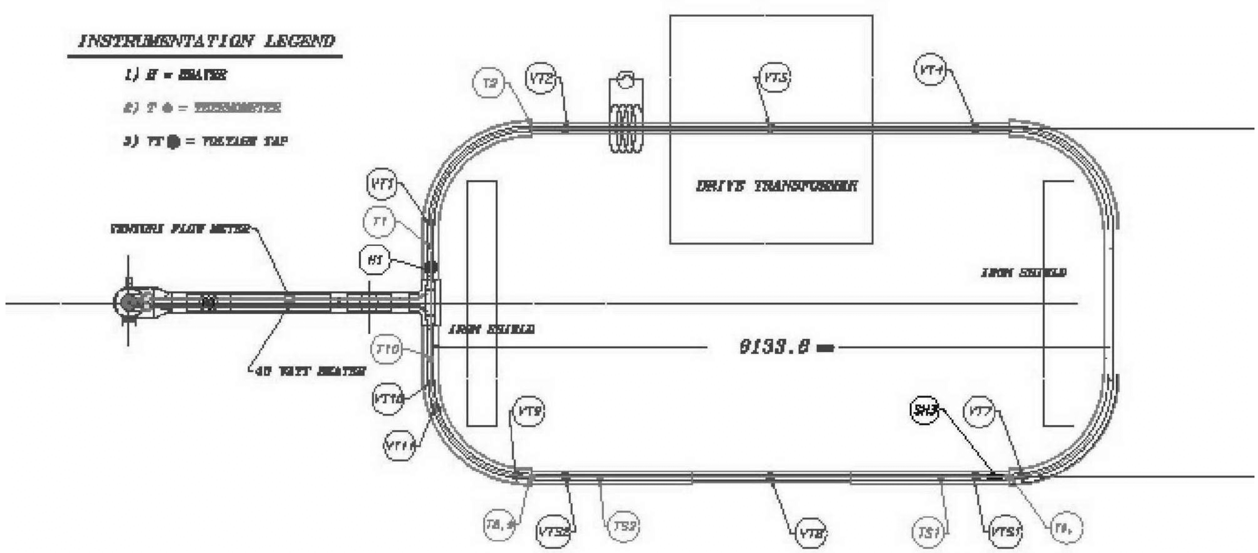
Fermilab Low-field NbTi superferric B ~ 2 T Other interesting ideas for superferric machines: KEK, JINR	Brookhaven Very high field B ~ 12.5 T Goal: based on future development of YBCO "conductor friendly" common coil
Fermilab High-Field Nb_3Sn $\cos\theta$ B ~ 11 T	Lawrence Berkeley Lab Very high field B > 13 T various materials being tried: Nb_3Sn, Nb_3Al, BSCCO "conductor friendly" common coil
	Texas Stress management B ~ 16 T



All the high field approaches use brittle materials. The Gupta invention of the common coil approach was an important step for the eventual use in accelerator magnets of HTS or A15 materials.

The difficult 3-D bends of saddle coils are avoided. The bending radii are of the order of the bore spacing rather than the bore dimensions which also eases demands on the coil winding process.

The Fermilab low field (2.0 T, transmission-line magnets) program is making progress. Nearing completion is a test loop in the MW-9 building built using surplus SSC conductor. The loop has a removable 4-m section in which various transmission lines can be tested.



The main issues in magnet development can be summarized.

- Material (Nb_3Sn, Nb_3Al, HTS) development (and cost reduction) is essential for the high field approach.

- How small can the aperture be? For high field the space between the usable aperture and the inside of the coils is about right for the necessary beam screen.

- Dynamic range -- how far can this be extended? This is a serious issue in magnets built with A15 or HTS materials

Interesting new approaches to the vlhc emerged at the November Magnet Technologies workshop:

- Gupta combines the advantages of good low field performance in an iron-dominated gap with a conductor-dominated gap to achieve high fields and synchrotron radiation damping at collision energy. The result is a 4-gap magnet with large dynamic range.
- Dugan and Syphers proposed a full energy injector. This would, of course, require two tunnels. The 50 TeV injector would be built from simple, single aperture, superferric devices where injector performance is not crucial because of radiation damping in the collider. In the collider a smaller high-field magnet aperture is possible. This would mean lower currents and smaller forces. Perhaps most important, the high-field magnets are dc and the field can be optimized at a single operating point.

Accelerator Physics Considerations

Transverse Mode Coupling Instability (TMCI)

The strong head-tail instability appears from the defocusing effect of wake fields induced by bunch head on bunch tail particles. Synchrotron motion, i.e. exchange of particles between head and tail helps to avoid the instability.

TMCI has been observed in electron storage rings but not (yet) in proton storage rings. For proton machines, there may be factors such as incoherent tune spread due to direct space charge or beam-beam interactions that increase the TMCI threshold.

Shiltsev & his colleagues have proposed a number of solutions.

Transverse Coupled Bunch Instability

Growth times vary as $f^{-1/2}$ (Marriner) so only low frequencies need to be considered (higher modes will be dealt with using a "conventional" single turn delay bunch-by-bunch damper). For low frequency, rapid growth modes, a set of feedback systems spaced around the circumference will handle the problem.

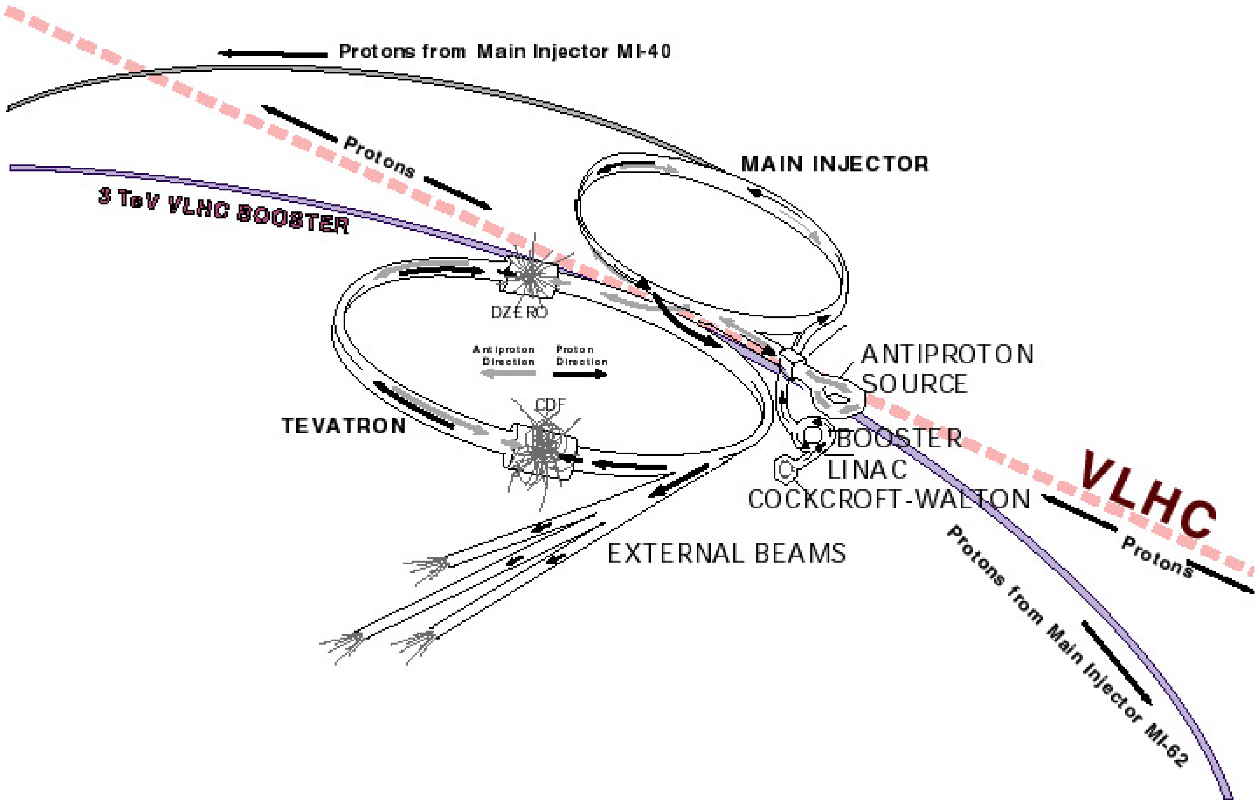
Noise and emittance preservation

The Fermilab region is seismically stable. A vibration free environment is important to minimize emittance growth problems.

Recent measurements (**10^{-3} Hz - 1 kHz**) (Novosibirsk - SLAC - FNAL collaboration led by V. Shiltsev) show that either high or low field machines are feasible at the chosen depth. Measurements are being extended to lower frequency, **>10^{-7} Hz**, to understand if dynamic alignment will be necessary.

Excellence of the Fermilab site

- **Existence of the injector chain**
- **Excellent Geology**



Fermilab region geology

- predictable rock and tunneling conditions, relatively homogenous rock mass – extensive local experience in the TARP tunnels (> 100 miles under Chicago)

- no settlement problems at the depths being considered

- rate of movement of groundwater in the dolomite layer we are considering for the collider is very small (aquatard)

- choose depth so that 3 TeV and 50 TeV machines in same layer of dolomite. This is deliberate to avoid large vertical bends in the 3 TeV transfer lines

- two long (2-3 km) transfer lines from MI-62 and MI-40. FODO lattices using permanent magnet quads

- The direction from Fermilab for the 50 TeV ring is not yet determined and needs geology data over a wide geographic region.

- The 150-meter depth is comparable to the deeper of the LEP/LHC shafts.

Tunnels and Choice of tunnel size

- lowest cost
- room for other machines
- Sufficient room for installation and maintenance
- Operating the machine will certainly imply the use of robotics; just how much robotics is used is a matter of economics.

"Conventional" TBM/Conveyor belt tunneling

- ♦ we have used the specific siting and depth of the 34 km tunnel as a model to investigate tunnel costs

- ♦ we are using detailed cost model from Kenny Construction to understand cost drivers

- ♦ a recent study by the Robbins Company gives optimism that this cost (per meter of tunnel) can be significantly reduced

Safety is a major issue. The fewer the number of people underground the safer the job.

Goal: no people underground except during maintenance. The mining industry is moving toward totally robotic systems.

New concepts have emerged: in TBM's and in Muck Removal.

The Trenchless Technology (generally < 2m diameter) and the Tunneling industries are growing in importance as a practical solution to putting infrastructure underground with minimal surface disruption. These industries are in many ways driven by concern for the environment. Thus our efforts towards lowering the cost per meter of accelerator tunnel can have benefits to society beyond our needs.

Conclusions

What we agree on:

- a common goal of probing the microworld to nearly a μfermi
- a set of working parameters:

  50 TeV/beam; 3 TeV injector fed from the Fermilab MI; 10^{34}

The vlhc is <u>already</u> technically feasible
<u>THE</u> KEY ISSUE:
Lowering the cost measured in
\$/TeV

An International Effort

Already scientists from several countries are involved in the effort. There are many opportunities for increasing the world community of scientists and engineers participating in the vlhc effort.

Why work on vlhc now?

Typically 10-15 years elapse from first R&D magnet to last machine magnet.

It is not too soon to be working on a post-LHC collider although clearly construction would not begin until the first physics results come from LHC.

There is uncertainty in the future. We need to continue to pursue the VLHC option so that we can decide on the most informed long-term strategy.

We are looking at cost reduction strategies that would allow the machine to be built with technology that is already understood

and at the same time

at strategies that require new technology and probably have longer time scales, and unknown cost implications.

New technologies and new approaches are required to continue the dramatic rise in collider energies as represented by the Livingston Plot

Real benefits to society from vlhc R&D will help gain the necessary public support

There has been significant progress in the past 3 years

Innovative approaches are being suggested

R&D is underway

Proposals for future R&D are being generated